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Compression of Dehydrated Food Products

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Compression of Dehydrated Foods

Phase I Review of Literature

Research and Development Project DA19-129-QM-1630 (OI 5149)

by

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Abstract

This review covers all the work that has been carried out on the compression of dehydrated foods in the U. S. A., Canada, Australia and the United Kingdom. The advantages in compressing dehydrated food into blocks or bars were cited, as well as the problems which have been confronting all researchers in this field of investigation. Some of the major problems are mentioned for consideration in the experimental stage; e.g., the fragility of product, the effect of heat and compression on the final quality of the product.

Success has been claimed in compressing some products (at different laboratories) such as cabbage; furthermore, disappointments were reported in the trials to compress other dehydrated products such as potatoes.

The objectives of this study are to investigate the factors which affect the compression of selected dehydrated foods, and to develop techniques for compressing these food products on a pilot scale plant.

Introduction

Compression of dehydrated foods is a newly developing art which was introduced to the food industry in the late thirties. The British Ministry of Agriculture, Fisheries and Food, through the Experimental Factory in Aberdeen, has experimented with the compression of vegetables, especially cabbage, carrots; and fruit bars. During 1942-1943 Massachusetts Institute of Technology carried out a research program on the compression of dehydrated foods. Also, under the auspices of the Agricultural Research Administration, USDA, a food compression research project was initiated in 1943 which ended in 1944. The Defense Research Medical Laboratories in Canada have worked on the development of meat and fruit bars (24,25). The research group in this laboratory followed the recommendations for compressing granulated foods as published by the Aberdeen Laboratory in Scotland. Different patents for compressing dry food stuffs were claimed during the 1940's (2,5,16).

All the reports from England and the United States covered the advantages of compressing dehydrated foods; moreover, the problems which were encountered during compressing the different products were presented (1,3,29). The main purpose of compressing dehydrated foods was stated to be the reduction of bulk to save space during shipping or storage, and to feed the combat forces on land, sea, or in the air. While the importance of compressed foods has also been recognized in supplying scientific groups on expeditions such as crossing the Antarctic and climbing Mt. Everest, the interest in the United States faded away after 1944. The Aberdeen Laboratory research group has been reporting their progress in compressing dehydrated vegetables, fruits, and flour (4,6,9,10).

The U.S Army Quartermaster Corps developed in 1960 a new research project on the compressing of dehydrated foods. The objectives of this research are:

1. A review of literature for all published and unpublished work on compression of dehydrated foods.

2. A study of the factors which should be considered during the compressing of different dehydrated-ration components (vegetables, fruits and meats).

3. Developing specific procedures for compressing the various components mentioned above on an experimental scale.

4. Designing and developing pilot scale equipment for the compression of the products which were covered in this study.

Review of Literature

In this review the information is submitted under two main parts: The first part will deal with the different factors which are considered by the various investigators during compressing the dehydrated foods; and the second part will cover the techniques and findings which dealt with specific dehydrated foods.

I. FACTORS CONTROLLING THE FOOD COMPRESSING TECHNIQUES

1. Moisture Content

The production of low-moisture dehydrated foods has been one of the objectives of the food-drying industry because of the advantages of keeping the quality of dehydrated foods during storage. Nevertheless, moisture has been found to contribute tremendously to the coherence of the compressed dehydrated products. That is why most of the low moisture foods have been found to be brittle and, accordingly, not to yield readily to compression without destroying the character of the product. Foods of low soluble solids content, mainly sugars, have been found fragile when they contain moisture below 3%. Vegetables of all types (shredded, diced, sliced, etc.) were found to fragment easily at low moisture; for example, potato must contain at least 13% moisture in order to be compressed (1). Pulverized and powdery dehydrated foods are expected to be less affected by compression at low moisture content, however, egg powder of 2% moisture presented problems during compression (1).

During the latter part of the Second World War, it was the practice in Aberdeen Factory of Scotland to compress dehydrated cabbage and carrots after conditioning the product to 8% moisture by injecting steam in the heated air stream. Following the compression, all blocks were redehydrated for about 12 hours at 120° F. to reduce the moisture content to 6% (10,11). In the United States (1) potato and egg powders were compressed after adjusting the moisture content to 15%, then drying the blocks to less than 7%. Microbiological troubles and loss of quality were observed in compressed blocks with a relatively high moisture content. Proctor et. al. (23) emphasized in their reports the disadvantages of increasing the moisture content of dehydrated foods before compression. Gooding (7) stated in a recent report a new method of compressing cabbage without adding any moisture, and thus overcoming the drawbacks of the original method.

According to the U.S. Army Quartermaster Corps specifications for dehydrated foods, the maximum moisture allowed for various fruit and vegetable products is as follows:

1) Moisture not more than 6% -
White potatoes and garlic

2) Moisture not more than 5% - green and red peppers

3) Moisture not more than 4% - sweet peas, carrots, onions, sweet potatoes, lima beans, green beans, Navy beans, whole prunes, fruit mix.

4) Moisture not more than 2% - cabbage, apples, applesauce.

Meats presented a completely different picture when compression was applied at different moisture levels. Prater et. al. (22) found that compressing dehydrated mutton mince with low moisture levels (7% dry weight basis) yielded better blocks than that with medium (11%), and high moisture levels (14.5%). Nevertheless, this conclusion might not be valid when the precooked-dehydrated meat is compressed at lower moisture levels. According to the U.S. Quartermaster Corps precurement specification for ground precooked-dehydrated beef (28) the maximum moisture content to be allowed in the dried beef has been 2.25% (fat free basis).

2. TEMPERATURE OF THE PRODUCT

Heat has been known to be a deleterious factor for the fresh quality of foods. That is why all efforts were directed in food dehydration towards the use of low temperatures, however all reports agreed on heating the dehydrated products to optimal temperatures for conditioning before compression. The heat treatment of the products complemented the moisture effect in obtaining coherent blocks. The general idea of heat treatment was to plasticize the macromolecules in the products such as the proteins and starch to a degree which allows more cohesiveness, and thus keeping the acceptable characteristics of the dehydrated product. Unfortunately, the conditioning temperatures resulted in protein denaturation, and the gelatinization of starches which caused many difficulties in the food compression field because of their effects on the rehydrating quality of the product.

Ranges of temperatures that were found to be appropriate for conditioning different dehydrated foods before and during compression were reported by different laboratores (1,6,7,10). The MIT report (19) concluded that no product could be compressed satisfactorily unless it was heated to at least 135° F.; however, in another laboratory, dried tomato juice of 4% moisture content was compressed at room temperature and 1500 psi (33). Most of the dehydrated vegetables were found to compress satisfactorily if heated to 120-

160° F. (1), while dried fruits were compressed readily at room temperatures. Apparently, the optimal product-temperature for compression was determined by the character and chemical composition of the product. Proctor (23) concluded that fruits were compressed easily because of their high sugar content.

Dehydrated foods which were high in fat content required refrigeration before compression in order to avoid oil extrusion during compression (22,23,24). Prater et. al. (22) investigated the effect of temperature on the final quality of mutton blocks and found that none of the samples compressed at 36° F. and 500 psi collapsed after 1 hour of relaxation while out of the samples compressed at 77° F., eight blocks collapsed after 1 hour of relaxation (number of samples in each case 72). The same investigators reported in another part of their experimental work, that when they soaked the dried mince in the hot fat at 3 different temperatures (122, 140, and 158° F.) before compression, the mince compressed at 122° F. yielded the best quality of blocks. Donnelly (5) developed a method for debulking foods by refrigerating flaked, unseasoned mixed vegetables to approximately 20° F. then compressing at 1500 psi.

3. <u>COMPRESSION PRESSURES</u>

The reduction in volume of compressed dehydrated products was found to vary according to pressure (18), however, dwell period was found to be as important as pressure (1). Furthermore, it was proved that the higher the applied pressure, the shorter the dwell time required for satisfactory compressions. Pressures required for compressing dehydrated foods ranged from 200 to 5500 psi with dwell periods from 0-60 seconds. For example, good blocks of sweet potato (Puerto Rico variety) were obtained at pressures of 4000 psi and 600 psi for dwell periods of 3 and 30 seconds, respectively (1). Gooding (7) compressed dehydrated cabbage (3-4% moisture) at 160-170° F. and 4000 psi for 15 seconds, while in other work (1) dehydrated cabbage (3-5% moisture) was heated to 150° F. and compressed under 2250 psi for 3 seconds.

When Prater et. al. (22) experimented on the effects of pressures and dwell on the final state of dried-mutton blocks, the following results were obtained 1/.

1/ - From the mean scores for state of block table #5

Dwell Time (Min.)	Mean Scores After Relaxation Pressures (psi)				Number of blocks
	250	500	1000	2000	
	(56)	(38)	(22)	(12)	
0	.60	1.68	3.03	3.82	72
	(41)	(9)	(1)	(0)	
3	1.20	3.42	4.61	5.33	72

Numbers in brackets denote number of blocks which scored zero (collapsed).

It was obvious that the number of cohesive blocks paralleled the increase in pressures and dwell times, however, when the overall factors were examined, the investigators suggested that 500 psi for 3 minutes were the optimal conditions for compressing dried mutton mince.

4. BLOCK SIZE AND WEIGHT

The sizes of blocks were usually chosen according to the number of servings required from each block; moreover, the characteristics of the dehydrated product generally limited the final size, density, and weight of the compressed blocks. Fourteen-pound blocks of egg powder with the dimensions of 7" x 10" x 6" were compressed satisfactorily, nevertheless, this block size was impractical for cohesive products such as onions and apples in which "stack burn" was observed in the middle of the blocks. This "stack burn" was recognized by the brown color in the product, and it was caused by the long exposure to heat after compression since the core of the blocks required a long time to cool. The long time required for rehydration is another drawback for large blocks, moreover, some products (egg powder) did not rehydrate completely (1). One-pound blocks were found to be satisfactory for most of the products with dimensions about 3" x 5" x 2". Gooding and his collaborators in Scotland reached the conclusions that 1/2# discs of dehydrated cabbage with the dimensions of 5 7/8" diameter x 31/64" thickness were the best for quality and ease of rehydration. All blocks were designed to serve 25, 50, or 100 persons, however the current trend is to prepare blocks or discs to serve 6 to 25 persons (27). Such blocks will be 4 5/8" x 3 7/8" in lateral dimensions, and the thickness will differ according to the degree of compression, and product characteristics (27). Dehydrated vegetables were compressed in Australia into discs which averaged 3 3/4" in diameter, and ranged from 3/4" to 15/16" in thickness. Treadway et. al. (32) developed a method to compress potato chips into bars measuring approximately 3" x 1" x 5/8".

Bars of mixed dehydrated-fruits with sugar were also tried and processed by either block press or by cutting mats. The block method was found to be unsatisfactory, while the mat method proved to be promising (30). Fruit and meat bars were developed also in Canada. Both types of bars weighed 2 ounces with the dimensions of 3 1/8" x 1 1/2", and in thickness 11/16" and 3/4" for the fruit and meat bars, respectively. All dimensions and weights were allowed a tolerance of $\pm$ 1/16 of the unit. Recently survival wafers were compressed in the Western Regional Research Laboratory from wheat flour, which averaged 0.70 ounce (20 gms.) with a diameter of 2 1/4" and 1/4" thick 1/ (20).

5. ADDITIVES (PLASTICISERS)

Efforts to reduce the degree of fragmentation in low-moisture (3-4%) compressed foods included the addition of different components which will increase or develop plasticity in the dehydrated product. Gooding et. al. (9) obtained a better quality of compressed dehydrated cabbage when they scalded the cabbage, before dehydration, in a liquor containing 1-1.5% sugar, however, the final product was unacceptable because of sweetness and browning, especially at high temperature storage conditions.

Berg (2) claimed a patent for compressing cereals by adding 0.5-3% of ethylene or propylene glycol which improved the firmness of the compressed product. Birds Eye proposed in a patent to add glycerol to partially dehydrated vegetables which will be plastic when dried. Nevertheless, when Gooding (7) sprayed 120 ml. of a 5% glycerol solution to each pound of steam-blanched cabbage he found that browning occurred more readily especially at high storage temperature, e.g. 100°F. or under tropical climate conditions. Similar results were also obtained by Gooding (7) when he used a solution of 5% glycerol monoleate to plasticize blanched cabbage.

Fats have been used as binders in compressing wheat wafers (20), meat bars (24), and mutton blocks (21). All methods reccommended using high-melting fats such as animal fats or hard-shortenings in order to decrease the fat loss during compression. Prater et. al. (22) reported that better blocks of dried-mince mutton were obtained when the mince was soaked in fat at 122° F. for 5 minutes prior to compression.

Water, though it is not considered as an additive, improved the plasticity of the low-moisture dehydrated foods. The disad-

1/ Measured and calculated by the writer.

vantages of compressing high-moisture dehydrated foods were mentioned previously under moisture content.

6. MOLD DESIGN

Different mold designs were prepared for compressing dehydrated foods, however, the most accepted one was the floating female die design (1, 18). The Western Regional Research Laboratory Group (33) suggested using water-free, salt-free edible oils to lubricate new dies and thus reduce friction. For compressing powdery foods, the inner sides of the female boxes were designed with vertical grooves (1/32" x 1/32" and 7/8" apart) which facilitated the escape of air during compression. Moreover, the male dies were also prepared with perforation which led to vacuum lines and which helped in the elimination of air pockets.

Mold clearance recommended was about 0.01" which facilitated the escape of air during compression, while larger clearances caused jamming of the product between the male and female dies (1).

The MIT group suggested making the male die face in a convex shape in order to decrease the degree of expansion after compression, however, it was reported from other laboratories that this design did not lead to the claimed results (1,7).

All parts of the dies as well as the platen surfaces were heated to approximately 150° F. to maintain product temperature during compression. Some molds were designed with pins which could hold the plunger in position after the compression. These pins were to act as 'holding presses' to prevent relaxation of the blocks (7).

7. KIND OF PRESS

Two kinds of presses were tried to compress the different kinds of dehydrated foods. Conclusions reported by the MIT group (18,19) showed that the hydraulic press was more adaptable to compress all dehydrated foods, especially those with brittle character such as vegetables, than the mechanical press. The latter was found to be applicable in the case of powdery foods such as egg powder. Also, it was concluded that although the mechanical press was faster in operation, the blocks were inferior in quality to those compressed by the hydraulic press (23).

Laboratory scale presses were either hand operated or automatic. The presses' capacities ranged from 20 tons to 50 tons according to the scale of operation and size of blocks (7). Most of the presses used were of the up-stroke type, however, some

presses of the down-stroke type were used in compressing potato-chip bars (32).

During the second World War cocoa beverage powders were compressed in discs 5/8" thick with a screw type press which was used originally in the tile industry (17). Also, a huge rotary press was used at Doughboy Mills to compress vegetable soups and flour (13). Prater (21) used a small motor powered hydraulic press which is frequently used in the plastics industry.

8. VARIETY

Variety of vegetables or fruits was proved to be an important factor in determining the suitability of the dehydrated product for compression (1,7).

The suitability of different dehydrated potato varieties for compression was investigated (1). "Of the eastern grown varieties, Katahdin, Chippewa, Sebago, Bliss Triumph and Dakota Red, Bliss Triumph and Katahdin yielded products undesirably gray in color, and this grayness was accentuated on compression. Chippewa gave the most attractive product (1)." The effects of climatic conditions and probably cultural practices were illustrated when samples of the same varieties were obtained from Maryland and Maine States; and the blocks of Maryland samples were found to be more "attractive" and cohesive than those of the Maine samples. Moreover, the Russet Burbank variety obtained from the Pacific Northwest was superior in compression, color, and rehydration to all mentioned varieties (1).

Gooding (7) experimented on dehydrated-cabbage varieties and their effects on the final compressed blocks. He stated that out of the ten varieties (steam-scalded) assayed, only two of the Savoy type yielded unsatisfactory blocks. When the same investigator checked the combined effects of variety and method of scalding in the quality of the compressed blocks, he found that the method of scalding had a negligible effect relative to the variety.

Sweet potato varieties were shown (1) to vary tremendously on compression. The southern or moist type which is generally represented by the Puerto Rico variety yielded acceptable blocks while the dry type such as the Maryland Golden variety gave disappointing results under the same experimental conditions.

9. SCALDING (BLANCHING)

The only work directed to study the effects of scalding on the final quality of compressed foods was by Gooding (7). He concluded that steam blanching yielded a better quality of dehydrated and compressed cabbage than that quality obtained from water

scalded samples. Moreover, this investigator explained that the difference between the samples, within the same variety, was due to the leaching effect of the scalding water, which caused an increased fragmentation. To overcome this leaching effect, a licuor of 1-1.5% soluble solids was recommended for scalding, however, browning was observed in such samples especially when they were stored at high temperatures (100° F).

10. TESTS FOR EVALUATIONS

A. Density of the compressed product has been considered one of the important tests for compression evaluation. Density units were chosen as pounds per cubic foot in the U.S.A., and were expressed in grams per milliliter in the United Kingdom. Early in the 1940's the MIT research group (18) suggested the per cent reduction in volume as a scale to measure the compressibility of the different food products, however, the density scale has been found to be more practical since it shows the weights of the compressed food relative to its volume.

Another scale was suggested by the Western Regional Research Laboratory (33) in which the compression ratio was expressed by the density of the product after compression relative to the density before compression. This scale combines the aforementioned scales so that both the density and the reduction in volume are measured.

The highest density in the compressed product has always been the goal; however, there were limits beyond which it is inadvisable to compress the product. High compression might lead to lower palatability, poorer nutritive values, and slow rehydration (over an hour). Experimental work of the USDA groups showed that a range of 50-70 pcf (pounds per cubic foot) was obtained in most of the dehydrated foods assayed, and an average of 60 pcf was recommended for a final density after expansion or relaxation (1). In the United Kingdom, Gooding reported that cabbage has been compressed very satisfactorily to a density of 1.1-1.2 gm/ml and a compression ratio of about 1:8. The research Laboratory at Tasmania, Australia prepared samples of compressed cabbage, beets, parsnip and Swede turnip which ranged in density from 63.5 - 79.7 pound per cubic foot.1/ Prater et. al. (22) reported that dehydrated mutton and beef minces were compressed satisfactorily to densities of 0.8 - 0.9 gm/ml. Treadway (32) reported on the compression of potato chips into bars with density ranging from 1.0 to 1.3 gm/ml 2/ and a compression ratio of 1:20. The fruit bars in Canada were required to be 4.2 3/ pcf in density according to the purchase

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1/ Calculated from data acquired through the Quartermaster Institute in Chicago 2/ Calculated from data. 3/ Calculated from data.

specifications of the Department of National Defense (25). Evidently, the reported density ranges were the result of these factors: The pressure, dwell periods, and post compression treatment (cooling and/or holding press).

B. Free expansion of the compressed blocks was considered an important factor by most of the investigators in the U.S.A., and Australia, while the United Kingdom group found that expansion was a negligible factor in determining the final quality of the compressed products.

Trials to eliminate or reduce the post-compression expansion were the convex shape of the surface in the male die (18), a holding press to retain the shape of product surfaces until it was cool (1, 19) and cooling the product fast enough to stop the expansion. It was concluded that the male die shape was not effective in stopping expansion (1), while both the holding press and cooling were required to retain the block-compactness. The critical time for expansion was reported to be during the first to second minutes after compression (19). "Blocks of all products except certain fruits lose practically all tendency to expand when cool" (1). Rigid packages and compressing directly in-package were other factors considered to stop expansion(1).

Different holding presses were designed such as the pressure-roll conveyor (19), and the horizontal-loop conveyor (1).

C. Fragmentation of the dehydrated products during compression leads to the presence of "fines" after rehydration. Fines in vegetables were estimated as the percentage of the dried fragments which passed through a 4-mesh sieve (1), however, the Western Regional Research Laboratory defined the "fines" as the fragments which passed thru an 8 mesh screen (33). The high ratio of fines was considered an index to how much damage had occurred in the compressed product.

Damage such as the release of starch particles from the potato tissues caused problems in compressing dehydrated potatoes. Also the loss of flavor and nutritious values were mentioned as some of the other serious problems which were caused by fragmentation (1).

The tolerance for fines was reported to be not more than 5% in order to produce satisfactory blocks (33), while in other investigations (1,18,19) visual comparisons between the compressed and uncompressed rehydrated samples were considered satisfactory enough for evaluation.

Other factors such as moisture, temperature, pressure and dwell periods (1,19,7) affected the degree of fragmentation as well as the variety and method of scalding.

Fragility of the compressed meat bars has been tested in Canada (24) so that "a bar shall not crumble when picked up with the thumb and forefinger, placed on the narrow sides at approximately one inch from either end." Furthermore, all bars will be held at room temperature for one hour before the test.

D. Rehydration or reconstitution of the dehydrated products has been considered an important factor in determining the quality of compressed foods. A one pound food block would be considered satisfactorily compressed if it rehydrated within one hour (1). It was also reported that one ounce cubes of cabbage, carrots, green beans, and peas were rehydrated in boiling water for 5-10 minutes (26). Hot water was found to bring about a faster rate of reconstitution than the cold water. The degree of rehydration of both compressed and uncompressed products should be as close as possible in judging for the acceptability of compression.

E. Retention Pressure test was developed by the MIT laboratory to measure the degree of post-compression expansion, and to determine the pressures which were required for the holding press (see free expansion) (18,19). Prater (21) showed an instrument which was used in measuring changes in heights and diameters of dehydrated-mutton slice blocks during the post-compression period. The retention pressure was usually less than 10 psi (1,19) and accordingly light and inexpensive holding presses were designed.

F. Organoleptic-Quality tests were designed to judge the changes, if any, which might have taken place during compression. Trained taste panels graded the blocks before and after reconstitution according to these factors: color, odor, flavor, texture, and over all appearance which might include shape, cracking, and crumbling during handling (1,28). Furthermore, to evaluate the effect of compression on the nutritious values of the food products, the caloric values were estimated. A close positive relationship was found between the loss of flavor and the loss in soluble solids after rehydration (1).

11. PACKAGING AND STORAGE

During the second World War most of the dehydrated vegetables were packed in 5-gallon tin cans under vacuum. The MIT research group followed this method of packing compressed-dehydrated products, moreover, they suggested packing compressed foods in

cellophane or cartons (19). For better storage-life Isherwood (14) developed the method of coating the food blocks or packages with gelatin which was mixed with a plasticizing agent. Rigid packages were recommended by USDA (1) for packaging stone fruits (peaches, prunes, etc.) moreover, it was suggested that compression in the final container might be of help in eliminating the post-compression expansion. Gooding (7) packed 15 half-pound cabbage blocks in No. 10 tall can (603 x 904), and also used a 3# flat can for packaging 5 half pound blocks.

Many research workers have reported on the use of in-package desiccants to secure low moisture in dehydrated foods, however, only a few used these desiccants for compressed foods (1,8,12). Calcium oxide was found to be the most favorable desiccant because of its high capacity in absorbing water-vapor at low relative humidity (12,31). Specifications for the desiccant (CaO) were designed so that at least an increase of 28.5% in weight was required within a period of 7 days when the desiccant was placed in a closed container (desiccator) over a saturated solution of sodium bromide at 24°C. Creped Kraft paper with a stretch in both directions of not less than 15% or a jean cloth bag with a Kraft paper liner have been used successfully so far for in-package desiccants(20). Experiments on the effect of the distance between the desiccant and the food on the drying rates (in air packs) showed that drying rates decreased as the distance increased, while in the vacuum packs the distance between the desiccant and food had no significant effect on the rate of drying (1). Hendel and Burr (12) summarized the advantages of using in-package desiccants in the following: "Protection against non-enzymatic browning of dehydrated foods, against the development of off-flavors in orange juice powder, against the caking of fruit and vegetable powders, and against losses of sulfite and ascorbic acid." Gooding and Duckworth (8) confirmed that in-package desiccation reduced the rate of deterioration in flavor, texture, ascorbic acid content and color of dehydrated cabbage. The sacrifice of space which was occupied by the desiccant was 20% and 28% when cabbage was packed in #10 tall cans (7) and 5 gallon cans, respectively (1).

Oxygen-free packaging was also recommended in combination with in-package desiccation (1,12,8,9). Vacuum and nitrogen packaging have long been used to maintain the quality of dehydrated foods. Oxygen-scavengers (eliminators) were developed as a cheaper method to pack foods in the absence of oxygen; for example, Loo and Jackson (15) used sodium sulfite and copper sulfate to remove all trapped oxygen in a sealed [illegible] can of dry milk. A comparative study between the shelf life of beef-mince blocks, and uncompressed packs in air and nitrogen was carried out by Prater

and his collaborators (22). They found that both the small mince size and fat treatment extended the storage life of the blocks, however, the nitrogen packs surpassed the quality of the fat-treated blocks, the regular blocks, and the air pack. Gooding et. al. (9) reported that storage life of dehydrated food products depended on these factors:

a. Moisture content
b. Temperature of storage
c. Presence of oxygen (or air)
d. Ascorbic acid content

The significance of moisture contents and presence of oxygen (air) were previously discussed under the in-package and packaging part.

The effect of temperature on the storage life of compressed foods was investigated by Gooding and Duckworth (8). They found that the compressed cabbage samples with desiccant, developed more browning than the uncompressed samples which resulted from the relatively high moisture content in the compressed samples. Browning of the compressed blocks was also encountered in the samples which were compressed with glycerol and/or sugar; and were stored under tropical conditions, e.g. approximately 100° F. (7). Gooding et. al. (8) found that compression did not shorten the storage life of dehydrated carrot even when stored at high temperatures.

The extension of storage life by in-package desiccation was also investigated (8). A taste panel did not differentiate between the compressed samples stored with desiccant for 12 months at 37° C. and those stored without desiccant for only 2 months under the same conditions.

Ascorbic acid (a highly reducing compound) is easily oxidized to dehydroascorbic acid and thus reduces the amount of oxygen in the package. That is why ascorbic acid has been used in the food industry to delay the oxidation of coloring compounds which cause browning of products such as peaches and apples.

12. DEBULKING

The MIT research group suggested the method of debulking powdered or grained foods by using a vibrating table (18,19). The same investigators reported that 20% reduction in volume was achieved in the case of soups. Simultaneously, the research groups of USDA were experimenting independently on debulking of foods by jolting and/or vibrating the food-containers (1). They reported that the size and shape of the powder particles were

important in determining the final density, while moderate changes in the product moisture and temperature had no significant effect on the final product density. At present, sliced or flaked onions are debulked in #10 tins by vibration to a capacity of 1.4# per can for the slices, and 2.5# per can for the flakes (20).

II. SPECIFIC FOOD PRODUCTS AND THEIR CHARACTERISTICS DURING AND AFTER COMPRESSION

1. VEGETABLES

A. Cabbage

Most of the research on compression of dehydrated foods in the United Kingdom has been done on cabbage. Experiments on a prototype press yielded results which established a routine procedure now used for compressing cabbage (11). The cabbage shreds were heated to 160°-170° F. for one minute, then charged in the preheated mold (150° F.) which was compressed at 4000 psi for 15 seconds. The plunger was heated to 150° F. in order to avoid powdery fines on the block surface. Half-pound blocks were packed in #10 tall cans (15 blocks) or in 3# flat cans (5 blocks) without crumbling. The blocks were 5.94" in diameter by .55" thick with a density of 0.9 gm/ml and 4-5% moisture. Relaxation of blocks after compression was reported as follows:

Time	Thickness	Diameter
1 minute	0.49"	5.90"
10 minutes	0.50"	5.94"
1200 minutes	0.55"	5.94"

Accelerated storage conditions did not cause any serious deleterious effects on the quality of the blocks when compared with the uncompressed product.

In the United States, cabbage was compressed successfully by the USDA research group during the second World War period (1). Cabbage shreds containing 3.5% moisture were weighed at room temperature, then conditioned for half an hour at 150°F. (dry bulb) with 95°F. wet bulb temperature in a stream of air (approximately 600 feet per min.). The press parts were also heated to 150°F. then the cabbage was compressed at 2250 psi for 3 seconds. One pound blocks with a 60 pcf and 3.5% moisture were obtained with the dimensions of 3" x 5" x 2". Blocks were subjected to a holding press after they were ejected from the press, however, an expansion of 2.6% was recorded in both the length and width of the blocks.

The blocks disintegrated in water after 24 hours at 70°F. and after 18 minutes at 200°F. Organoleptic tests for both compressed and uncompressed samples, which were cooked for 10 minutes, showed no distinguishable differences.

B. Onions

So far, the only published work about the compression of onions was that of the USDA Laboratories (1). Results proved that onion flakes might be compressed successfully as follows:

The onion flakes were conditioned at 130°F. (dry bulb) and at 79° F. (wet bulb) for 15 minutes. Molds were charged and compressed under 700 psi with no dwell time, then the blocks were cooled while they were under the holding press which restrained expansion beyond a final density of 55# per cubic foot. Cooling of the blocks was advised to be under forced-convection system. One pound blocks of 3" x 5" dimensions expanded approximately 2.7% (in the lateral dimensions) and contained 4% moisture with a final density of 50 pcf. Compressed blocks disintegrated in water (200°F.) after 7 minutes, and organoleptic tests proved that the samples were highly acceptable.

Currently, Basic Vegetable Products, Inc. "compress" sliced onions in #10 tin after heating the slices to 130°-150° F. then pressing 1 3/4# in each can (20).

C. Green Beans

To our present knowledge, no published or unpublished work has been found concerning the compression of green beans, however, the characteristics of dried green beans might be helpful in determining the best conditions under which green beans might be compressed. Freeze-dried green beans were compressed recently into 1 ounce blocks (3 1/4" x 2 1/16" x 1 7/8") with a density of approximately 8.6* pcf (26).

D. Green peppers

The same status as green beans and further study is needed to know the characteristics of the dried product.

E. Carrots

Sliced, stripped, and diced carrots were compressed successfully under identical conditions by USDA Laboratories (1). Also,

*Calculated from data

results showed that carrots containing moisture lower than 4.5% yielded blocks with poor cohesive quality and low density. One pound blocks were obtained in high quality from sliced and diced carrots when compressed with 4.5 - 4.8% moisture. The recommended procedure included the preconditioning of carrots for 20 minutes at 150°F. (dry bulb) and 93° F. (wet bulb) in an air stream of 500 feet per minute; then compressing the carrots under 4000 psi for 3 seconds. Caution is required after the blocks were ejected from the press because they would fall apart unless they were subjected to the holding press until they were cool. This method restrained expansion to 3% and 25% lateral and height dimensions, respectively. Trials to stop expansion such as packaging directly after compression in tight-fitting cartons were unsuccessful. The blocks produced by this method averaged 3" x 5" x 1 3/4" and had a density of 60-70 pcf. Hot soak (200°F.) disintegrated the blocks in 10 minutes, and organoleptic tests were carried out on uncompressed and compressed carrots which were cooked for 15 minutes. No differences were detected between the uncompressed and compressed cooked samples; however, in a few cases incomplete rehydration caused a lower score for the compressed samples.

Preliminary results from the Aberdeen Laboratories (7) showed that satisfactory blocks of carrots were obtained when the product temperature was adjusted to 120° - 125° F. and compressed under 2000 psi for 15 seconds. Recently the same laboratory, in another report, concluded that 6" discs of carrots might be produced, without heating the molds, by heating the product to 150° F. and compressing under 2800 psi (11).

F. Peas

The only report about compressed peas was that of the U.S. Quartermaster Corps about "compressed Dehydrated Subsistance, Great Britain (26). One ounce freeze-dried peas were compressed in 3" x 2 1/4" x 1 1/8" blocks with a density of 14.5 pcf.* The blocks were reconstituted for 5 minutes in boiling water, then cooked for 2-5 minutes. The organoleptic panel graded the compressed samples between fair and good.

G. Navy Beans (Precooked), Lima and Red Kidney

None of these beans were reported to be compressed in any of the Laboratories which experimented on the compression of

*Calculated from data

dehydrated foods. Preliminary experimentation will be required to establish the optimal conditions for compression.

H. Corn

Dehydrated corn is a food product which has not been widely processed or used in the regular markets, however, it might be used in feeding the armed forces. Exploratory work will help in studying the optimal conditions for compressing corn.

I. Sweet Potatoes

The importance of variety and dryness of the sweet potatoes for compression were emphasized in the USDA report (1). It was found that both "the dry and the freshly dug moist type are less readily compressed into cohesive blocks." The best procedure for compressing diced Puerto Rico sweet potatoes (moist variety) was to heat the product at 150° F. (dry bulb) and 105°F. (wet bulb) in a stream of air (500 fpm) for 20 minutes. The conditioned product was directly compressed under 3000-4000 psi with a dwell time between 3-15 seconds. The blocks were 1.7" x 3" x 5" in dimensions, 65 pcf in density, and contained 4% moisture. The lateral expansion of the cooled blocks ranged from 2-5%. The blocks were soaked for 10 minutes in hot water (200°F.) and cooked for 10 minutes at boiling temperature. No significant difference was detected between the compressed and uncompressed samples, however, deleterious changes to flavor and texture were noticed when the blocks were compressed under 3800 psi.

No recommendations for compressing diced dry-type sweet potatoes were reported, however, the preliminary studies indicated that pressures lower than 1000 psi yielded unsatisfactory blocks. Moreover, relatively high moisture (7.1%) content and conditioning at 160° F. did not produce good coherent blocks, and the fines increased from 1.8% in the uncompressed samples to about 5% in the compressed samples.

J. Irish Potatoes

The big problem which confronted the different laboratories (7,1,11) in compressing dehydrated potatoes originated mainly from the characteristics of the product. The chemical composition, especially the starch and sugar contents varied according to many factors such as the variety, climatic condition, cultural practices, and last but not least the post-harvest treatment. It might be expected too, that the types of starch, e.g. linear and branched or waxy, and their ratios in the dehydrated samples will determine

the acceptability of one variety for compression over another. Gooding (7) reported that when potato strips (3 1/16" x 5/16") of 13% moisture were compressed at 140° F. and under 200 psi he obtained blocks which were variable in behavior so that some blocks disintegrated "rapidly" in cold or hot water, while others required 10-12 hours for reconstitution. According to the Quartermaster Standards for Procurement [illegible] 6% is the maximum moisture [illegible] allowed in dehydrated potatoes (28). In order to meet such standards and overcome the difficulty of compressing potatoes at such low moisture [illegible] the Research groups in U.S.D.A. (1) compressed diced or stripped potatoes at 9-15% moisture then dried the blocks to a 7% moisture level. The same investigators classified potatoes into two groups according to the total sugar content:

A. Low-sugar potato, not more than 4%
B. High-sugar potato, higher than 4%.

In group A it was found that 13% moisture and temperature of 140° F. (dry bulb) were required to form satisfactory blocks, while in Group B, 9% moisture and temperature of 160° F. (dry bulb) would be needed to obtain similar blocks.

Generally speaking, the optimal conditions for compressing low sugar potatoes started by heating the product to 150° F. (dry bulb) with 14% moisture content and compressing under 800 psi for 3 seconds. The blocks were subjected to a holding press until cool, then dried in a vacuum shelf-drier or a cabinet drier to 7% moisture. Drying time in vacuo varied according to the initial moisture content from 4-7 hours. The dried blocks averaged 50 pcf in density, moreover, they were rated acceptable organoleptically and physically (for reconstitution). One pound blocks disintegrated in hot-soak (200° F.) within 45 minutes and were cooked for 5-10 minutes for grading.

K. Mixed Vegetables

Trials to compress potato and carrot strips were made in the Aberdeen Laboratory (7,10,11). Good blocks were obtained when a mixture of 1/8" carrot strips and 3/16" potato strips were heated to 140° F. and compressed under 1000 psi for 30 seconds dwell. Similar blocks were obtained by compressing 1/4" potato dice with 3/16" carrot strips. The blocks measured 57 x 48 mm, and 30.5 mm in thickness after 24 hours. The final density was 0.95 gm/ml, and no troubles were found in the reconstitution and cooking.

2. FRUITS

A. Apples

Dehydrated apple nuggets were compressed satisfactorily in the U.S.A. by the following method (1): apple nuggets of 1.8% moisture were weighed in wire-mesh baskets, then conditioned at 130° F. and 73° F. for dry and wet bulb temperatures, respectively. After 20 minutes, the product was transferred to the molds (heated to 120° F.) and compressed under 1200 psi with no dwell time. The blocks were restrained from expansion until cool in a holding press. One pound blocks measured 3" x 5" x 2.1" with a final density of 65 pcf, and were reconstituted in hot-water (200°F.) for 25 minutes. No changes in flavor, color, texture, appearance, or rehydration ratios were detected when compared with the uncompressed samples.

B. Apricots

Apricot halves (13.2% moisture) were compressed successfully at room temperature under 300 psi for 15 seconds. The blocks were packaged after being ejected from the press, then boxed directly and the final density of blocks averaged 75 pcf. No deleterious effects on the quality of apricots were detected under these conditions, contrary to the injury of skins when 1500 psi pressures were applied at room temperature, or 900 psi at 120°F. (1).

C. Peaches

Peach-halves were compressed as readily as apricots at room temperature, even at lower moisture contents (10.7%). Four-ounce blocks were compressed at room temperature under 300 psi pressure for 30 seconds. The blocks were wrapped and boxed directly to hold expansion to a minimum, and the final density of the blocks was 73 pcf. Both the compressed and uncompressed samples were reconstituted for 17½ hours (no mention for water temperature) (1).

D. Prunes

Poor cohesiveness in dehydrated prune blocks was the major problem that was not found in compressing the other stone-fruits (apricots, peaches). Whole prunes of 12.4% moisture were compressed into 16 pound blocks at room temperature and 300 psi for 30 seconds. Rapid wrapping and boxing eliminated the problem of expansion and disintegration before packaging. Compressing

directly in containers was suggested to overcome the "fragility" of the blocks and in the meantime to retain a high density of 73 pcf. The container walls would be protected during compressing with a sleeve which could be backed up by a mold outside the container. Only a 100 psi pressure for 1 minute would be required in this method since only a fairly cohesive block was needed in the container (1).

3. PRECOOKED GROUND BEEF, MUTTON AND PORK

Granular dehydrated "meat-pork" mixture was chilled, in cracked ice, then compressed into approximately 5.5 x 4.7 Cm. of lateral dimensions (4). The blocks were packed directly in flexible-film bags under nitrogen atmosphere. Problems of extruding fat during pressing, and stickiness, were eliminated greatly by chilling the meat granules before compression.

Prater (21) studied the effects of moisture content, fat, slice size, and pressures on the compression of dehydrated mutton slices. This investigator concluded that the most desirable blocks were produced under these conditions; precooked dried slices (0.1 - 0.15") were compressed under 252 psi for 3-5 minutes. The meat blocks were cooled, after ejection, in a blast of air at a temperature of 32°F. The blocks were approximately 3½ times as dense as the uncompressed samples, and contained 6.0 - 7.4% moisture plus 21.5 - 22.2% fat.

Recently Prater et. al. (22) published the results of compressing dehydrated mutton and beef mince. The investigators studied the effects of fat and water content, size of mince, temperature of mince, pressure and dwell on the final characteristics of dried mutton mince. Results showed that the recommended procedure to compress mutton mince which would be packed in rigid containers was as follows: Mutton was minced through ¼" diameter holes in mincing plates; the mince contained 38-40% (dry weight basis) and 11% (dry weight, fat-free basis) natural fat and moisture, respectively. The meat was cooled to approximately 30°F. and compressed at 500 psi for 3 minutes. Nevertheless, the same investigators recommended the following method to compress mutton mince: ¼" mince of 38-40% fat, and 11% moisture contents soaked in fat at 122° F. for 5 minutes. The excess fat was drained and the mince was pressed (die temperature at 122° F.) at 250 psi for 5 minutes. The blocks were sealed in cans which were cooled in a cold air blast.

Cooked meat bars (mixed ground beef and pork or pure beef) were prepared in Canada (24) according to the following procedure:

Sliced meat (1"-2" slices) was cooked in steam for 20-30 minutes, then chilled quickly. The cooking liquor was concentrated to 1/5 of the meat weight, and the liquor was prepared to gravy by adding salt, monosodium glutamate, and a preservative (BHA, propyl gallate). The cooked meat was ground through a 3/8" diameter plate and dehydrated (with the gravy) in hot air to a moisture content of less than 5%. Fat content was adjusted to 40% with beef fat or lard, and the meat was chilled to a temperature below 40° F. before compression. Two ounce bars were compressed under 1300 psi ± 100 lb. for 10 seconds. The bars measured 3 1/8" x 1 1/2" and were wrapped immediately after compression in heat-sealed pouch-type bags.

4. MEAT AND VEGETABLE MIXES

Gooding (6) reported on his experiments on a meat and vegetable block, and concluded that a satisfactory mixture was composed of:

Dehydrated beef		40.00%
"	potato strips (3/32" x 5/16")	35.00%
"	carrot strips (3/32" x 5/16")	12.00%
"	onion flakes	7.50%
"	mixed herbs	0.45%
Salt		5.00%
Pepper		0.50%

The mixture was heated to 60-70° C. and compressed in cold molds (4.6 x 5.6 cm) at 2000 psi for 30 seconds. Blocks (2.8 cm thick and density of 1.1 gm/ml) were reconstituted in cold water which was boiled gently for 30 minutes.

Current Ideas and General Considerations on the Compression of Dehydrated Foods

New Methods in dehydrating foods such as freeze drying created a major problem for food compression since compression will positively change the fragile character of the dried product. Nevertheless, reports from Aberdeen Scotland (26) maintained that freeze-dried carrots of 5% moisture content were compressed quite well. When the moisture content was lowered to 1-2%, the material became shattered even under the mildest conditions of compression. It will be expected that the "templates" of the freeze-dried product will be destroyed after compression, and accordingly the rehydrating quality of such product will be extremely decreased.

The higher quality of dehydrated foods today will require more critical conditions for compression relative to those conditions recommended during the second World War. Low-temperature treatments especially in the final stages of drying helped to obtain better qualities, especially for flavor and color. Generally speaking, all methods developed during and after the second World War recommended conditioning the product (specifically vegetables) at 135° - 160° F. which might have been detrimental to the quality of the product at the low moisture content of 3-5%.

Compressing the dehydrated products directly in 5 gallon cans (as practiced during the second World War) was considered by many processors to be damaging to the quality of the compressed product. The "stack burn" in compressed onion-slices, and discoloration in shredded cabbage are cited examples (20). This problem, however, was eliminated when both aforementioned products were compressed in #10 tin cans, but the difficulty in removing the virtually solid blocks from the cans remained a continuing problem. At present one processor[1/] produces a dense pack of onion slices and flakes by conditioning the product at 130-150° F., then pressing 1 3/4 and 2 1/2 pounds of sliced and flaked onions in #10 tin cans respectively.

The new feeding concepts adopted by the Quartermaster Food & Container Institute (QMC) for the Armed Forces are (27):

1. The Quick-serve meals which are prepared from precooked dehydrated items, and which are enough to serve either 6 or 25 men.

2. The unitized meals which are prepared from uncooked

1/ Basic Vegetable Product, Inc. Vacaville, California

dehydrated items, especially meats, and which serve 25 men.

Both types of meals will be packed in flexible film and foil bags enclosed in bellows-type cartons. It will be convenient to compress the quick-serve meals directly in the package because the blocks will not be removed and rather will be reconstituted directly in the package. The following examples are abstracted from the only available data on precooked compressed vegetables and which were reported by QMC (26):

Dehydrated Subsistence in Great Britain

Item	Wt. (oz)	Cube (in^3)	Cooked Cube (in^3)	Ratio Cooked/Dry
Carrots (precooked)	1	1.9	12.6	6.6
Swedes (precooked)	1	1.85	18.1	9.7

The dimensions of the foil lined carton are 7½" in height (within 1" from the top edge), 3 15/16" in width, and 4 11/16" in length so that the total available volume is 138.5 cubic inches or 0.0801 cubic foot. Also the block dimensions will be 3 7/8" wide x 4 5/8" long, and assuming that the height will be 1", then the block volume will average 17.9 cubic inches or 0.0104 cubic foot. The ratio between the volume of compressed block to the maximum volume in the carton is $\frac{.0104}{.0801}$ or approximately 1:8. From the preceding calculations it is quite obvious that a block of 9.4 ounces of carrots (precooked) may be compressed directly in the package without volume problems after rehydration. 1/

Dehydrated fruits may be compressed directly in the flexible package as well as the precooked meals. Attention will be directed towards the use of higher pressures and lower temperatures in order to avoid any scorching or discoloration.

Efforts to eliminate or decrease the heat which develops during the compression process will include a perforated bottom-plate for the mold in order to allow for a fast escape of air. Also, as the blocks eject from the mold they will be refrigerated. Cooling will cut down the rate of relaxation or expansion as well as the damaging effects of heat on the product quality. This method will be used in reducing the degree of expansion in both types of blocks (discs and rectangular blocks), moreover, the discs should be packed directly in #2 1/2 cans in order to control relaxation of the blocks.

1/ Calculated from data

BIBLIOGRAPHY

1. Agricultural Research Administration, U.S.D.A., Miscellaneous Publication 647; Experimental Compression of Dehydrated Foods (1948)

2. Berg, I. A.
Compressed Cereal. U.S. Patent 2,437,150 March 2, (1948)

3. Compression of dehydrated foods will save shipping space, Food Ind. 15,74 (1943)

4. Dalgleish, J. M.
Mechanisation of meat block production. Unclassified Report. SA/DA/RM/54. Ministry of Agric. Fisheries, and Food. Great Britain (1953).

5. Donnelly, J. C.
Debulking food for packaging. U.S. Patent 2,433,348, Dec. 30, (1947)

6. Gooding, E.G.B.
Meat and vegetable blocks. Unclassified report SA/DA/RM/31, Ministry of Agric., Fisheries and Food. Great Britain (1952)

7. Gooding, E.G.B.
Problems of cabbage dehydration. Food Manuf. 30,311 (1955)

8. Gooding, E.G.B. and Duckworth, R. B.
The effect of in-package desiccation on the storage properties of compressed and uncompressed dehydrated cabbage. J. Sci. Food Agric. 9,14-18 (1958)

9. Gooding, E.G.B., Duckworth, R.B., MacDougall, D.G. and Casey, J. The storage life of dehydrated vegetables III. Unclassified Report SA/DA/RM/82, Ministry of Agric., Fisheries and Food. Great Britain (1958)

10. Gooding, E.G.B., and Rolfe, E.J.
Some recent work on dehydration in the United Kingdom. Food Tech. 11,302-6 (1957)

11. Hay, J. M.
The compression of dehydrated cabbage, Unclassified Report SA/DA/RM/90. Ministry of Agric., Fisheries and Food. Great Britain. (1958)

12. Hendel, C. E. and Burr, H. K.
In-package desiccation of dehydrated foods, Ag. Res. Service, U.S.D.A., Cir. AIC-373 (1954).

13. Huge rotary press at Doughboy Mills, Food Packer, p. 39 July (1944).

14. Isherwood, F. A.
Preservation and storage of Perishable Materials. C.A. 40: 411[9]. Brit. Patent 561,966 June 13, (1944)

15. Loo, C. C. and Jackson, Wm. P.
Oxygen removers for packaged dry food products, U.S. Patent 2,825,651 March 4, (1958).

16. Marshall, D. E.
Compacting pulverized materials, U.S. Patent 2,594,956 April 29, (1952)

17. Mickus, R. R. and White, W. H.
Compression helps to solve Army-ration problems. Food Ind. 17 #10. 1147 (1945)

18. Massachusetts Institute of Technology, Compression of Dehydrated foods, Report No. 1 (1942)

19. Massachusetts Institute of Technology, Compression of Dehydrated foods, Report No. 2 (1943)

20. Personal Contact

21. Prater, A. R.
Compression of dehydrated mutton slices, Aus. J. Appl. Sci. Vol. 4, 603-11 (1953)

22. Prater, A. R., Coote, G. G., and Roberts, E. A. Compression of dehydrated mutton and beef mince, technical paper #10. Division of Food Preservation and Transport, Commonwealth Sc. and Industrial Res. Organization, Australia (1959).

23. Proctor, B. E. and Sluder, J. C.
The Compression of dehydrated foods, Proc. Inst. Food Tech. 132-42 (1943)

24. Purchase description for meat, pressed, Dept. of Natl. Defense (DND-M-7d) Canada (1960)

25. Purchase description for fruit, pressed, Dept. of Natl. Defense (DND-F-8a) Canada (1960)

26. Quartermaster Food & Container Inst. for the Armed Forces, Compressed dehydrated subsistence, Foreign material report NR. 137-59 (1959).

27. Quartermaster Food & Container Inst. for the Armed Forces Brochure, Feeding systems to meet new tactical needs, Feb. (1960).

28. Quartermaster Food & Container Inst. for the Armed Forces Military Specifications for procurement of vegetables, fruits and meats.

29. Rushton, E., Stanley, E. C. and Scott, A. W. Compressed dehydrated vegetable blocks, the application of high frequency heating, Chem. & Ind. Vol 23, 274-6 (1945).

30. Self, R., Ralley, H. L. J. and Joyce, A. E. Fruit bar report, covering period 1956-1958, Unclassified Report SA/DA/RM/86. Ministry of Agric., Fisheries and Food. Great Britain (1958)

31. Talburt, W. F., Hendel, C. E. and Legault, R. R., Desiccating in the package, Food Eng. 28, 79-81, 194, 197 (1954)

32. Treadway, R. H., Wagner, J. R., Woodward, C. F., Heisler, E. C., and Hopkins, R. M., Development and evaluation of potato chip bars, Food Tech. 12, 479-82 (1958)

33. Western Regional Research Laboratory, U.S.D.A., How to Compress Foods, Food Ind., 15, 64-5, 130 (1943)